Phoenix Location Determination Using HiRISE Imagery

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Abstract

This investigation looked into determining Phoenix's position using an image (shown above) taken by the University of Arizona's High Resolution Imaging Science Experiment camera. The objective was to test how accurately a position for the lander could be determined during entry, descent, and landing to provide an alternate means of position determination independent of Phoenix navigation data or Phoenix telemetry in the event of the spacecraft's on-board inertial measurement unit failing or a communications breakdown that prevented the return of the data.

Method

Determining the position of the Phoenix lander from the Phoenix Descent Image required four steps:

1) Determining the location of the HiRISE camera (i.e. MRO's position in its orbit),
2) Anchoring the Phoenix Descent Image to the topography of Mars,
3) Calculating the line-of-sight along which the Phoenix lander appeared, as well as its position on the surface of Mars as it appeared to the HiRISE camera,
4) Using the resolution of the image to calculate where along this line-of-sight vector the Phoenix lander was positioned.

Anchoring the Phoenix Descent Image to the Martian Topography

Since the location of Heimdal Crater on Mars is known, four reference points were chosen around the edge of the crater in the original Phoenix Descent Image such that the Phoenix lander was placed at the intersection of the horizontal and vertical lines. The two horizontal line reference points are labeled H-H1 and H-H2. The two vertical line reference points are labeled H-V1 and H-V2. These points were used to measure the resolution of the image and provide a scale with which to measure the size of the Phoenix lander on the parachute.

After choosing the reference points, the Phoenix Descent Image was projected onto the surface of Mars. Once the Phoenix Descent Image was projected onto the surface of Mars, the location of Phoenix on the surface as it appeared from the HiRISE camera was easily found, and the final projected image resolution was 0.792382 m/pixel.

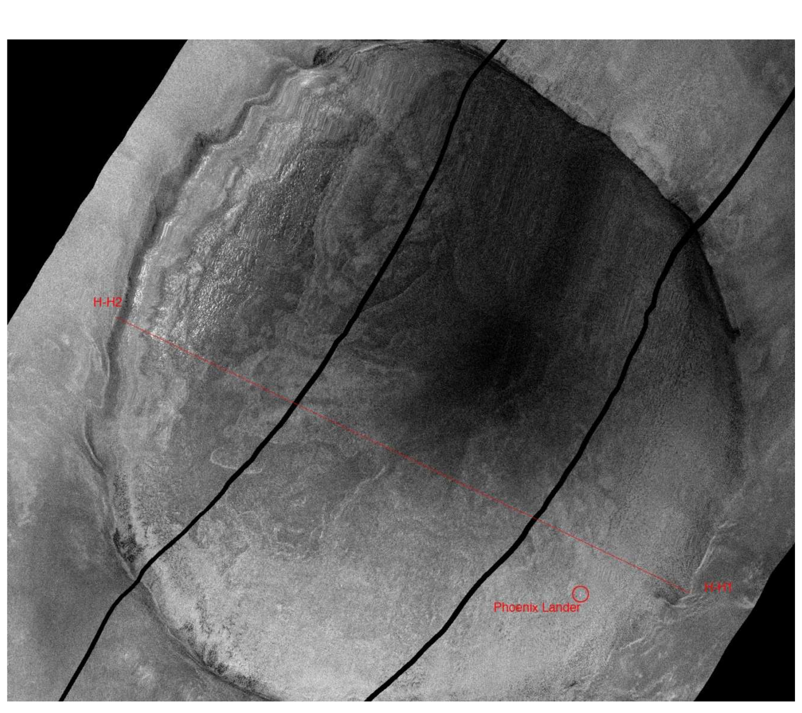
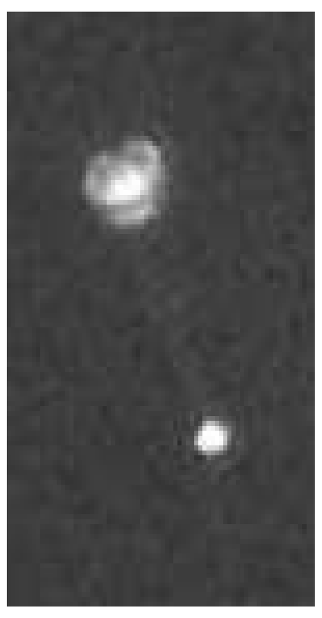


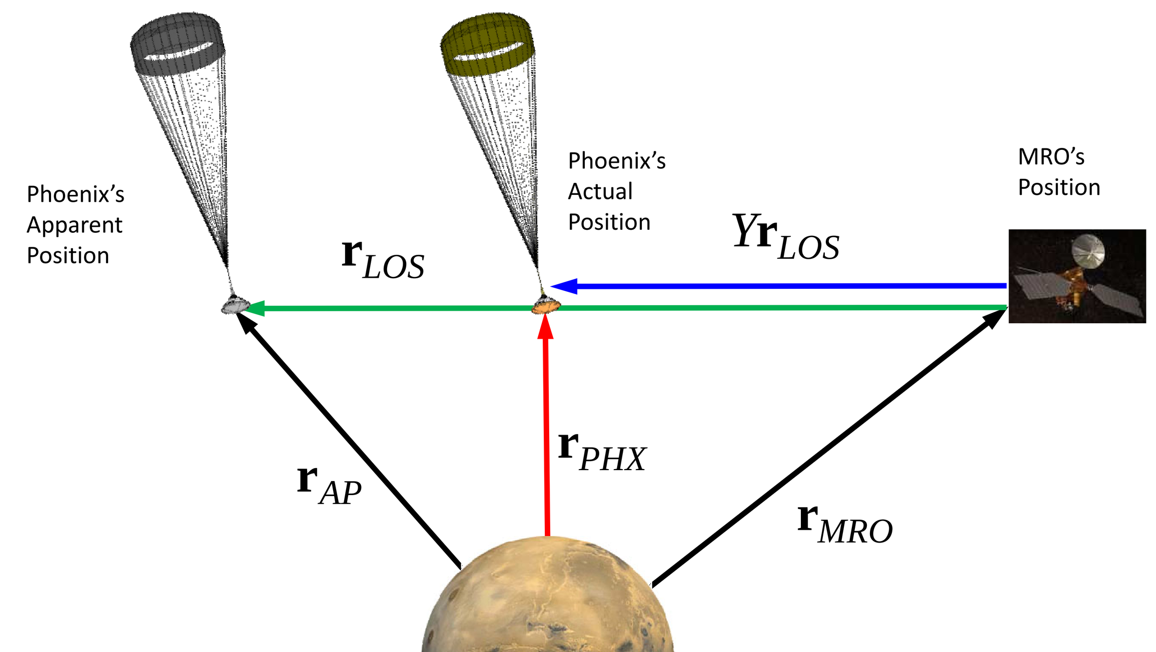
Image Resolution of Phoenix

The position of the Phoenix lander can be found using the resolution of the Phoenix Descent Image. Since the Phoenix lander lies in front of Heimdal Crater in space, it should be imaged with a higher resolution. Therefore, if the distance between the lander and the top of the parachute, for example, is known, the resolution at which the Phoenix lander was imaged can be found. The ratio (Y) of the Heimdal Crater resolution (ρ_{HC}) to the Phoenix lander resolution (ρ_{PHX}) can then be used to determine how far along the line-of-sight vector Phoenix lies in space. Adding this scaled line-of-sight-vector to the position of MRO, we have the actual position of Phoenix when the Phoenix Descent Image was taken.



The diameter of Phoenix's parachute is approximately 11.8 m. Using this distance as a baseline, the distance between the lander and the maximum diameter of the parachute can be estimated to be 31.5 m. However, since Phoenix is not hanging vertically in the plane of the image, the resolution of the image must be determined using the foreshortened distance between the lander and the parachute. From the image, the Phoenix lander on its parachute is rotated approximately 22.13° counterclockwise in the plane of the image. Out of the plane of the image, the Phoenix lander on its parachute is rotated approximately 32.28° such that the parachute is closer to the viewer than the lander.

These two angles define a cuboid which has two faces parallel to the plane of the image, and whose main diagonal is equal to 31.5 m. Therefore, in the plane of the image, the distance between the Phoenix lander and the maximum diameter of its parachute is approximately 27.19 m. This gives the resolution of the Phoenix lander (ρ_{PHX}) as 0.767 m/pixel with 35.46 pixels as the average pixel distance from the Phoenix lander to its parachute.

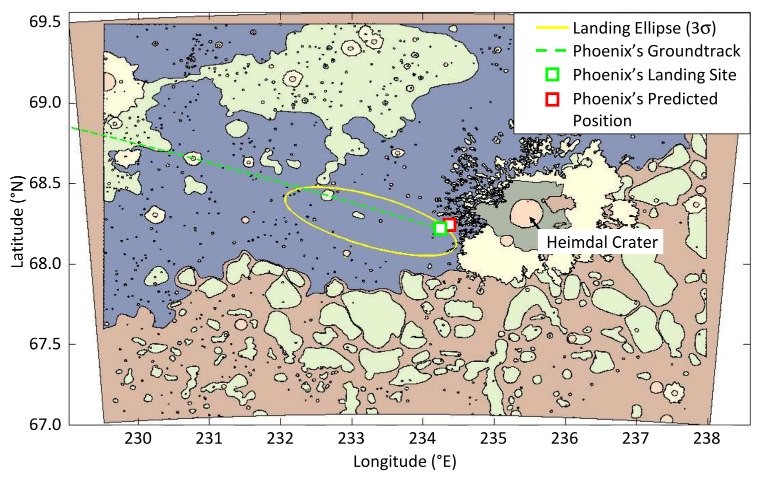


$$Y = \frac{\rho_{PHX}}{\rho_{HC}}$$

$$\mathbf{r}_{PHX} = \mathbf{r}_{MRO} + Y\mathbf{r}_{LOS}$$

Final Position Determination

Having found the Heimdal Crater resolution and the Phoenix lander resolution, their ratio (Y) is 0.9675. This places Phoenix at approximately 68.2525°N, 234.3979°E at a radius of 3386.495 km. This position places the Phoenix lander approximately 773 km from MRO and approximately 26 km in front of its apparent position in Heimdal Crater from HiRISE's viewpoint at the time the Phoenix Descent Image was taken. Phoenix's altitude was approximately 10.2 km above the surrounding terrain, and the overland distance from the landing site was approximately 3.8 km.



Conclusion

This investigation demonstrated that determining Phoenix's position using the Phoenix Descent Image was possible. The position of the Phoenix lander could have been determined independently of Phoenix navigation data or Phoenix telemetry in the event of the spacecraft's on-board inertial measurement unit failing or a communications breakdown that prevented the return of the data. However, position accuracy was affected considerably by knowledge of the orientation and dynamics of the Phoenix lander on its parachute. Using photogrammetry to accurately predict the position of planetary probes during descent could be improved with higher resolution images. Multiple images taken by two of more orbiting spacecraft would also improve position determination. Multiple images might also eliminate the need for both higher resolution images and precise knowledge of the dynamics of a planetary probe descending on its parachute.

Acknowledgments

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Error Considerations

Several sources of error are apparent in determining the position of the Phoenix lander from the Phoenix Descent Image. These sources of error include:

1) Uncertainty in the position of MRO at the time the Phoenix Descent Image was taken,
2) Distortion effects from image compilation and projection onto the topography of Mars,
3) Uncertainty in the distance between the lander and the maximum diameter of the parachute, and
4) Uncertainty in determining the resolution of the images of Heimdal Crater and the Phoenix lander (from the previous two sources of error).

Of all these sources of error, by far, the largest source of error was the uncertainty in the distance between the lander and the maximum diameter of the parachute. The apparent distance between the lander and the maximum diameter of the parachute in the image could be changed up to approximately one meter by extreme wrist mode oscillations, for example. If the distance between the lander and the maximum diameter of the parachute at the time of image capture is, for example, 30 m instead of the estimated 31.5 m (a change of only 1.5 m), the position of the Phoenix lander changes by approximately 35 km. Note that for the Phoenix lander to be at its apparent position in Heimdal Crater, the distance between the lander and the maximum diameter of the parachute would have to have been approximately 32.6 m (only 1.1 m greater than estimated) as shown below.